FINAL REPORT

for

TIME CODE STUDY

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## TIME CODE STUDY


### Summary

The first phase of the Time Code Study, covered in the First Semiannual Report (15 Sept 1964 - 28 May 1965) presents a survey and analysis of the techniques used in time code generation, recording, decoding, transmission and distribution with particular attention to the time code formats used. An analysis of time code characteristics is presented in terms of time code formats which are in general use.

The second phase of the study, covered by this report, presents a survey of timing systems at the various national ranges, service ranges, and NASA facilities. The subsystems at these facilities are classified and categorized in accordance with their types and functions.

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## I. INTRODUCTION

The first phase of the Time Code Study was presented in the First Semi-annual Report (15 Sept 1964 - 28 May 1965) and the supplement to that report.

The final report contains information regarding the second phase of the study. The objective of the second phase of the study is to compile information on timing systems in tracking stations and missile test ranges and to classify and categorize the subsystems in accordance with their types and functions.

The report is divided into two major areas: (1) a Summary of Time Code Generation Techniques, and (2) a Summary of Time Code Distribution Techniques.

Table 1, Time Code Generation, is a tabulation of the characteristics of the time code generation systems at the various test facilities and is the center of the Summary of Time Code Generation Techniques.

Table 2, Time Code Distribution by Radio Circuits, and Table 3, Time Code Distribution by Wire Circuits, are tabulations of the radio and wire distribution systems at the various test facilities and are the center of the Summary of Time Code Distribution Techniques.

## II. SUMMARY OF FIRST SEMIANNUAL REPORT AND SUPPLEMENT

The First Semiannual Report and Supplement (15 Sept 1964 - 28 May 1965) presents two basic sections as follows:

- Section I, Survey and Analysis of General Timing Topics
  - Time Code Generation Techniques
  - Recording of Time Codes
  - Time Code Decoding and Data Processing Techniques
  - Time Transmission from Station to Station
  - Time Code Distribution Within a Station
- Section II, System Analysis
  - Description of Time Code Formats
  - Analysis of Time Code Formats
  - Preliminary Analysis of Timing Accuracy

The supplementary material expands certain ideas presented in the First Semiannual Report.

## III. SUMMARY OF TIME CODE GENERATION TECHNIQUES

### A. GENERAL

All of the test ranges and data facilities considered in the study use essentially the same techniques for the generation of time code signals with relatively minor variations from the basic time code generation techniques discussed in Section II A 1 of the First Semiannual Report. The major differences in the time code generation systems are in the techniques used to achieve generation reliability such as redundant frequency sources, redundant generator channels, and the techniques used to switch the distribution system from one channel to the other. This section of the time code study will emphasize these areas.

### B. TIME CODE GENERATION TABLE

#### 1. General

Table 1 summarizes the major characteristics of the time code generation and code comparison subsystems at the test ranges and data gathering facilities considered in the study. This section of the study will discuss each characteristic or major feature in terms of the various types and categories of subsystems used at the various test facilities.

#### 2. Time Codes Generated

A Description of Time Code Formats and an Analysis of Time Code Formats are presented in Section III A and B of the First Semiannual Report. The paragraph entitled "Status of Existing

TIME CODE GENERATION

TABLE 1

| FACILITY | TIME CODES GENERATED (GENERAL PURPOSE) | FREQUENCY STANDARD TYPE, MODEL AND STABILITY | VLF | SYNCHRONIZATION | ADVANCE/RETARD | SIMULTANEITY OF GENERATOR OUTPUTS | NUMBER OF GENERATOR CHANNELS | TYPE OF ERROR DETECTION | TYPE OF CHANNEL SWITCHOVER | BATTERY BACKUP | OPERATOR ERROR PROTECTION |
|---|---|---|---|---|---|---|---|---|---|---|---|
| AFETR Cape Kennedy | IRIG A,B,C,D,E,F (both width and pulse position coded) IRIG A,B (Presence-absence coding) AMR A1,A2,B1,B2,C1,C2 D1,D2,D5,D6,E1,E2,E3,E4 PA517 500pps, 17 bit, binary sec PA521 500pps, 21 bit, binary sec PA117 100pps, 17 bit, binary sec | Crystal oscillators are used to drive the generators. Typical types in use are: Western Electric AN/URQ-11 ITEK 105 & 106, Frequency Electronics FE1100A, Manson RD 180 & CFS-180, General Radio 1115B. Crystal oscillators in use have aging rates ranging from $1x10^{-10}$ to $1x10^{-11}$ per day. Frequency standard at Eleuthera Island site is Varian V-4700A Rubidium Vapor Freq.Std. (stability $5x10^{-11}$ per year). National Co.Automichron used as precision frequency source for CW Radar Data. | Yes | Loran C closed loop system with Loran C tracking receiver. WWV | Digital circuits and resolver at 100kHz. | ± 1usec | Dual channel | | Manual switchover of individual signal on detected error. | Oscillator, generator and distribution sources, 15 minutes | Key disables all controls. |
| NASA Merritt Island Launch Area (Cape Kennedy) | IRIG A,B,C,D,E (No control bits) AMR A1,A2,B1,B2,C1,C2 D1,D5. | Sulzer 5A and Frequency Electronics FE-1100A crystal oscillators to drive generators. National Co. NC-1601 Cesium oscillator for frequency standard. | Yes | Loran C UHF Signal from AFETR WWV | Digital circuits and resolver at 100kHz. | 0.1usec clocked outputs. | Dual channel | Majority Logic compares channel A & B and AFETR UHF signal for code equivalency and time coincidence ±10usecs. | Automatic selection of Channel A or B,whichever agrees with AFETR time. | Oscillator,PRD, and Accumulators. | Key disables all controls. |
| AFPGC Eglin AFB | New system. IRIG A,B,C,D 27 bit parallel. Binary coded, hours, minutes, seconds, milliseconds. | Cyrstal oscillators, Manson RD-180 | Yes | Loran C WWV | Digital plus resolver, ±0.1usec with good reference. | 0.8usec | Single channel per site. Multiple sites. | | | None | Plastic shield over controls. |
| AFFTC Edwards AFB | IRIG A,B,C,D,E,F Center Format A, Askania Code, (1000pps). | Crystal oscillators to drive generators HP 107 BR | Yes | WWV Loran C (future) | Digital circuits and resolver at 100kHz. | ±0.1usec clocked outputs | Three channels | Automatic comparison of demultiplexed IRIG A,B,C and Askania Code. Amplitude monitor all signals. | Automatic switchover of all signals to secondary generator on detected error. | Essential circuits battery backed for 40 minutes. Stand-by ac generator | |
| NOTS China Lake | IRIG A,B,C,D | Crystal oscillators Reeves-Hoffman 2.5MHz | Yes | WWV Loran C | Digital circuits and resolver at 100kHz. | ±1usec | Single channel | | | Backup of primary generator system. | Recessed controls and disable switch. |
| PMR Point Mugu | IRIG A,B,C,D,E | Three Rubidium controlled oscillators,General Technology 304B, to drive generators. HP5060A Cesium Beam standard to be added. | Yes | Loran C WWV Traveling clock. | Digital circuits and resolver at 100kHz. | | Dual channel | | | Backup of two RB freq. standards and reference clock only. Stand-by ac generator | |
| WSMR | IRIG A,B,C,D,E WSMRG2 WSMR Cinetheodolite Dual Lift-offs | Rubidium oscillator General Technology 304B, stability $\pm 3x10^{-11}$/month drives all generators. | Yes | Loran C (Time) Tracking receiver WWV Traveling clock. | Digital circuits and resolver at 100kHz. | ±1usec | Three channel | Automatic comparison IRIG signals (sine and dc shift). All generators multiplex comparison phase and information. | Automatic switchover to secondary generator on detected error. | Battery on Rubidium standard and minor counters of all generators. Stand-by ac generator.(Programmed May 66). | All controls are at inaccessible control panel. |
| NASA Goldstone Tracking Station (Deep Space) | NASA 36 Bit BCD NASA 28 Bit BCD NASA 20 Bit BCD | Rubidium oscillator, Varian V-4700A, stability approximately $5x10^{-11}$/year | Yes | WWV | Digital circuits and resolver at 100kHz. | Clocked outputs | Single channel and reference clock | Manual | | Backup of RB standard and reference clock | Plastic shield over controls. |
| NASA Mojave Tracking Station (Minitrak Orbital) | NASA 36 Bit BCD NASA Serial Decimal | Crystal oscillator | | WWV | | | | | | | |
| NASA George C. Marshall Space Flight Center | IRIG A,B,C AMR B1,D3 | Two HP5060A Cesium Beam oscillators with two Manson RD-180 crystal oscillators as stand-by. Cesium beams are A.1 and HP K10-117A. Time scale translators converts to UT2. | Yes | WWV | Digital circuits and resolver at 100kHz. | ± 1usec | Three channel | Automatic comparison of 1pps phase and amplitude. | Automatic switchover of all signals to secondary generator on detected error | | Recessed controls and disable switch. |

Time Code Formats" on page 59 summarizes the use of the time code formats at the various test facilities.

3. Frequency Standards

The term "frequency standard" as applied to time code generation systems refers to the precision oscillator whose output is used to drive the dividing and counting circuits in the time code generator. The term is also used for the precision oscillator which is sometimes used as a secondary standard in a timing system. Some fundamental characteristics of these oscillators are presented in the Supplement to the First Semiannual Report on page 1.

Most facilities use one or more crystal oscillators to drive the actual time code generators and use atomic oscillators (either rubidium or cesium beam) as secondary frequency standards to which the crystal oscillators are compared. Crystal oscillators have been used as the operational precision signal source in the immediate past because they have been more reliable and considerably less expensive than atomic oscillators. Also because of the lesser cost, it has been feasible to use multiple crystal oscillators in multiple channel timing systems to provide the actual time code signals and use a single highly stable (and more expensive) atomic oscillator as a secondary standard for system frequency control.

The atomic oscillators are, however, continuously becoming more reliable and less expensive. It is presently feasible to use such an oscillator as an operational signal source as is the case at White Sands Missile Range.

4. VLF Frequency Control

Practically all of the test ranges and data gathering facilities utilize the stabilized VLF radio transmissions. As pointed out in the paragraph entitled "Time Generator Synchronization" on page 7 of the First Semiannual Report, VLF has been limited to the role of frequency control and has not been used extensively for time synchronization.

Time synchronization or the process of setting the generator 1 pps signal "on time" has been accomplished up to the present by means of WWV and Loran-C radio transmissions and traveling clocks. VLF transmissions have been used to <u>maintain</u> time synchronization once established.

The National Bureau of Standards and Goddard Space Flight Center have developed and have been investigating a system utilizing dual-channel VLF transmissions as a means of achieving time synchronization. The system under study utilizes the simultaneous reception of either 19.9 and 20.0 kHz or 20.0 and 20.5 kHz from Radio Station WWVL at Fort Collins, Colorado.

5. Synchronization

Time code generator synchronization techniques are described briefly in the paragraph entitled "Time Generator Synchronization" on page 7 of the First Semiannual Report and in the section entitled "Synchronization of Time Code Generators by Manual Versus Automatic Methods" on page 3 of the supplement to the First Semiannual Report.

Practically all of the timing facilities are currently using Loran-C transmissions for synchronization. Some facilities are using Loran-C tracking receivers, while others are using simple 100 kHz TRF receivers and interpreting the received signal visually.

Several of the facilities have had traveling clock visits for synchronization. This activity will increase considerably in the near future.

Practically all facilities retain the WWV receivers in the timing stations.

The Naval Observatory is designated as the reference for determining epoch time for all Department of Defense facilities.

PMR has been designated as the west coast reference station by the Naval Observatory and will maintain epoch time as defined by the Naval Observatory.

Regular checks at 90-day intervals by means of Naval Observatory traveling clock trips will be made to certify epoch time at PMR. PMR has budgeted for cesium beam precision frequency sources to better maintain the certified epoch.

PMR will be an official monitor of the Hawaiian Loran-C chain. The Master Station of this chain is located at Johnston Island and was recently equipped to radiate a 1 pps epoch signal as initially calibrated by Naval Observatory personnel using a traveling clock. This Johnston Island 1 pps epoch signal is maintained by the use of cesium beam frequency standards. The 59,600 microsecond repetition period of the Hawaiian chain will also be derived from the cesium beam frequency standard and will be useful in verifying epoch time with an ambiguity of 200 microseconds.

6. Generator Advance/Retard Circuits

Advance/retard circuits are discussed on page 11 of the First Semiannual Report.

The time code generators at practically all facilities utilize digital advance/retard circuits capable of providing coarse and fine advance or retard rates coupled with a continuously variable resolver operating at a 100 kHz rate as described in the First Semiannual Report.

7. Simultaneity of Generator Outputs

This subject is discussed in the paragraph entitled "Degree of Coherency Between Generator Outputs" on page 15 of the First

Semiannual Report and in the paragraph entitled "Simultaneity of Generator Outputs" on page 6 of the Supplement to the First Semiannual Report.

The time code generators in use at the various timing facilities are of both the type where all outputs are clocked and the type where outputs are derived from a normal binary chain. Generators with clocked outputs have typical outputs which are simultaneous within ±0.1 μsecond. Generators whose outputs are not clocked, typically have outputs that are simultaneous to within ±1 μsecond.

8. Multichannel Timing Systems

The most generally used method of providing timing reliability at the various test facilities is the use of additional timing channels in the system and incorporating some method of comparing the outputs of the several channels to determine the best channel to use at any given time. The most commonly used idea is to design the channels as separate identical units. The main advantage of this technique is that either a one-channel, a two-channel, or a three-channel time generating system can be implemented, depending on the requirements of each specific operation.

The method used for comparing the outputs of the several timing channels can be simple or more sophisticated, also depending on the reliability requirements.

Redundancy in time generating systems can be used to increase the reliability of (1) maintaining generator synchronization, and (2) maintaining timing service.

Maintaining synchronization is usually the most important consideration in operations where precise synchronization is required, such as satellite tracking stations. In such operations re-establishing synchronization, if lost, usually represents the loss of considerable time and effort. In such cases, the loss of synchronization is more important than the loss of timing service, that is, the actual time code outputs themselves. Usually the accumulator can be restarted and timing service re-established after a failure more readily than synchronization can be re-established.

Maintaining timing service might be the most important consideration in general laboratory applications where precise synchronization is not as important. In such applications, especially where a single time generator is providing timing information which is distributed to many independent users, maintaining reliable timing service might well be the most important consideration.

We feel that the most satisfactory means of using redundancy to increase the reliability of maintaining synchronization and timing service is to incorporate several independent channels in the timing system. As mentioned above, the basic advantage of this technique is that either a simple single-channel system or a more sophisticated three-channel system can be implemented using the same basic time code generator, depending on the reliability required for each operation. A second advantage of using separate units to implement a multichannel system is that the power supplies for the various channels can be completely separate. In general, we have found that it is better to keep as much separation as possible (both physical and electrical) between the channels of multichannel timing systems.

Single-Channel System

Some of the test facilities find that a single-channel time code generation system is adequate for the type of service required. In most cases the single-channel systems are driven by a good crystal oscillator monitored by VLF transmissions, contain means of resynchronizing the generator in the event of failure, and are provided with battery backup.

Dual-Channel Timing System

Additional reliability in maintaining synchronization and timing signals for distribution is achieved at several of the test facilities by the use of dual-channel timing systems. The typical system contains two identical time code generators.

Comparison of the timing signals from the two timing channels is limited to a determination that the signals compare or do not compare. If they do compare, then, obviously, both generators are correct (the probability that the same error occurred in both channels at the same time is very low). If they do not compare, an indication of error is provided and the operator knows only that one or both of the generators is not correct.

Some facilities maintain a separate reference clock which provides a 1 pps output as a third channel for comparison in determining which of two channels has lost synchronization.

Three-Channel Timing System

The three-channel system is probably the practical limit for redundant channels. With three channels, the channel in error can be detected, assuming that the probability of the same error occurring in two channels at the same time is very low. A three-channel system provided with battery backup and an atomic standard and auxiliary reference divider would provide the ultimate reliability in maintaining synchronization and timing signals.

9. Code Comparison Error Detection

The nature and extent of the error detection and code comparison circuitry in multichannel timing systems covers the entire range from a manual observation of individual outputs with an oscilloscope and a manual switchover to the good channel, to a completely automatic comparison and automatic switchover. The extent of the error detection and the comparison circuitry is dictated by the timing reliability required.

The degree of phase coherency required of the code comparison circuits should be consistent with the nature of the frequency standards used to drive the timing channels. For example, if crystal oscillators having a stability of 1 part in $10^{10}$ were used for the frequency standards, the generators could be expected to drift apart approximately 4 $\mu$sec in a day. Therefore, if the comparator was designed to provide an alarm with a time error of 10 $\mu$sec, daily correction of time error would be required.

The minimum error detection and code comparison system that is used in a two or three-channel timing system is one that compares only the basic 1 pps signal from each generator in amplitude and phase. This comparison shows only that the generators are operative down to the 1 pps point and are in synchronism with each other.

The next measure of additional reliability is attained by:

(1) comparing the major serial time code outputs (in the dc level shift form) in a serial comparator in amplitude and phase, and by

(2) monitoring the outputs of the modulated carrier output

of the major code with a threshold detector to determine that the output is present or absent.

Such a system indicates that the generators are in synchronism, that the accumulators are in agreement, and that at least the major code scanner and associated modulator and driver circuits are operative.

The ultimate error detection and code comparison system (1) compares all dc level shift outputs in amplitude and phase -- this includes all serial code outputs in the dc level shift form and all auxiliary pulse rates, and (2) monitors all modulated or sine wave outputs with individual threshold detector circuits to determine presence or absence of each signal. In this system, all output signals are either compared bit by bit or monitored for presence or absence and, when used in a three-channel system, should locate any type of failure in one of the three systems.

10. Timing Signal Switchover

In multichannel timing systems, the switchover point or place where the redundancy ends is usually at the output of the time code generator units and preceding the distribution system. This has been the case in most systems because the various distribution amplifiers are basically more reliable than generator outputs. (There are many stages and many circuits involved in generating the codes at the generator outputs and only one or two stages involved in each distribution amplifier.)

Various types of switchover systems have been implemented. Switchover can be made on an individual signal basis or on a complete generator basis. Most present day multichannel systems provide for switchover of all output from one generator to another if any error is detected in the first generator. The main advantage with this system is that all outputs are in synchronism at any given time. Another advantage is that complete switchover frees the faulty generator for corrective maintenance.

The switchover mechanism itself can be anything from a manually operated multipole switch or a bank of relays to logic switches programmed in such a way that the actual switchover occurs at a point in the code outputs where switching transients are minimized.

## B. DESCRIPTION OF REPRESENTATIVE SYSTEMS

### 1. General

This section of the Time Code Study presents a brief description of representative time code generation systems which are in existence at some of the National Ranges, Service Ranges, and NASA facilities listed in Table 1.

IRIG Document Number 103-59, Instrumentation Timing Systems Brochure, is presently in the process of revision and will contain more complete information regarding the majority of these timing systems.

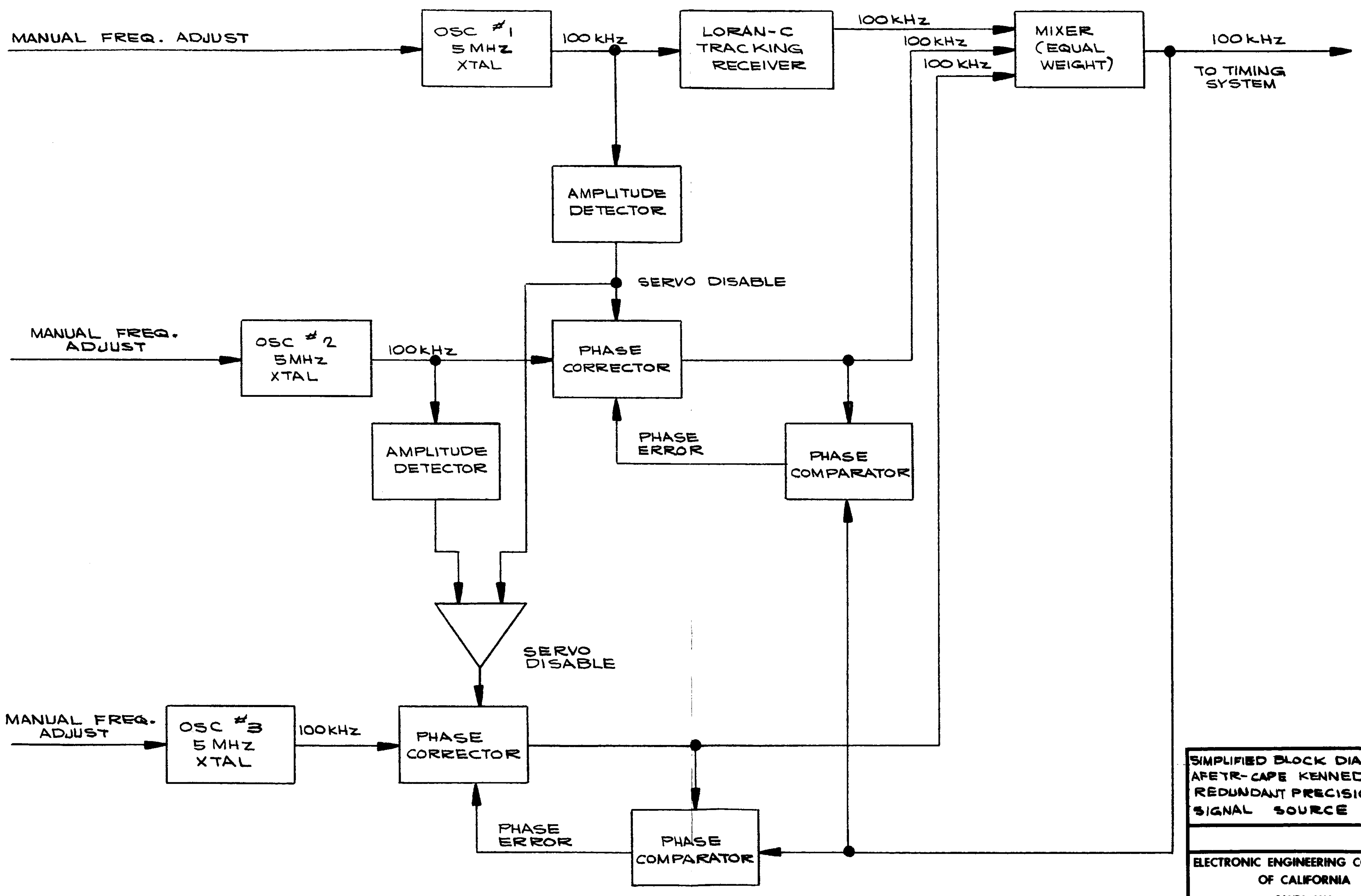
2. Air Force Eastern Test Range -- Cape Kennedy

AFETR presently utilizes a separate time code generation facility at each major complex throughout the range. Each generator is independently synchronized to WWV and East Coast Loran-C signals.

Time signals are distributed to areas within 10 miles of each central generator by means of telephone lines. Distribution of time signals within a radius of 40 miles is made by means of a time multiplexed system transmitted by UHF radio. These subsystems are discussed in Section IV of this report.

Each central time generation facility contains a dual channel time code generator. Each generator provides all the necessary signals to generate IRIG A, B, C, D, E, and the proposed IRIG F code as well as the AMR codes which are still required on the range. (Primary codes are tabulated in Table I.) AFETR is gradually phasing out the AMR codes in preference to the IRIG codes.

The dual channel time code generator at each central generation facility is driven by a precision 100 kHz signal derived from the outputs of three 5 mHz crystal oscillators which are mixed in a linear mixer and phase corrected to the Loran-C transmission. Figure 1 is a simplified block diagram of this subsystem. The




SIMPLIFIED BLOCK DIAGRAM
AFETR-CAPE KENNEDY
REDUNDANT PRECISION
SIGNAL SOURCE

ELECTRONIC ENGINEERING COMPANY
OF CALIFORNIA
SANTA ANA

DWG NO. FIG. 1

output of Oscillator #1 is phase corrected by a Loran-C tracking receiver to be in phase with the Loran-C carrier and applied to the linear mixer. The outputs of the other two oscillators are each routed through a phase corrector and applied to the linear mixer. The mixed output of the three signals is then used as a reference signal to phase correct the outputs of Oscillator #2 and Oscillator #3.

Oscillator #1 is normally the "master oscillator." If this oscillator output fails the amplitude detector disables the servo associated with Oscillator #2 and this oscillator output becomes the reference for Oscillator #3.

The precision frequency signals are also compared with standard VLF transmissions by means of VLF phase tracking receivers.

The dual time code generator 1 pps outputs are also synchronized to "on time" by means of the East Coast Loran-C transmissions. Thus, the AFETR timing system is tied to the East Coast Loran-C chain for both frequency and time information.

The present timing requirements at AFETR put more emphasis on accuracy of timing rate (incremental time accuracy) than on time synchronization. Many of the projects being supported at AFETR are more concerned with velocity and/or acceleration of a nearly orbital vehicle than with its actual location in space.

While AFETR will strive for time synchronization of delivered time codes on the order of 1 microsecond, should a substantial synchronization error occur, the computer programs in use check for time bias in multi-source data. If a definite time bias is detected, then this bias is subtracted for all subsequent data.

Like outputs of the two time code generators at each central timing facility are compared in amplitude and phase and an error indicated where signals do not compare. Manual switchover of the particular signal from one generator to the other is made after the operator determines which output is in error.

3. NASA Merritt Island Launch Area -- Cape Kennedy

Timing signals at Merritt Island Launch Area are generated by a central time generation station and two subcentral time generation stations. The two subcentral stations are synchronized by early signals transmitted from the central time generation station and delayed to provide signals which are on time with the central time generation system.

Timing signals are distributed from the central time generation system and the subcentral time generation systems to timing terminal units at remote instrumentation sites by means of telephone lines. This subsystem is described in Section IV of this report.

The Central Timing Station contains a dual channel time code generation system as well as a UHF radio receiver and a timing terminal unit which provides time codes from the AFETR, time division multiplex distribution system. Like time codes from each of these three sources are compared automatically. All timing signals are derived from the time code generator (either generator A or generator B) which agrees with the time codes received from AFETR.

Crystal oscillators with stabilities of from 1 to 2 parts in $10^{10}$ per day are used to drive the time code generators. The frequency of these signals is monitored by means of VLF receivers.

Generator synchronization is obtained from the AFETR UHF distribution system and is monitored by means of Loran-C and WWV radio transmissions.

4. Air Force Flight Test Center -- Edwards Air Force Base

Timing signals are generated at AFFTC by a three-channel time code generation system at a central timing station and distributed throughout the range by means of a time division multiplex system via UHF radio. The distribution system is described in Section IV of this report.

The three time code generator channels are designated as the "primary" channel, the "secondary" channel, and the "comparator" channel. The "primary" and the "secondary"cchannels are each driven by crystal oscillators with a published stability specification of ±5 parts in $10^{10}$ per day. The oscillator which drives the "secondary" time code generation channel also drives the comparator channel.

The primary and secondary channels each generate eight time codes (tabulation in Table 1) and several pulse rates and sine wave outputs. The comparator channel generates five of the time code outputs (IRIG A, B, C, E, and the Askania code). These codes are compared serially with similar codes from both primary and secondary generators and time code distribution is switched from the primary generator to the secondary generator when a specified number of successive errors is detected in any one of the primary generator outputs. Switchover is also accomplished if any one of the primary generator outputs have a variation from normal amplitude of more than ±25%. When any of the compared outputs have time differences of greater than ten microseconds, a visual and audible alarm is given.

Synchronization is accomplished by means of WWV and Loran-C radio transmissions. Frequency control is achieved by monitoring VLF radio transmissions.

5. White Sands Missile Range

Timing signals at WSMR are generated using a three-channel time code generation system. All three channels are presently driven by a single rubidium controlled oscillator as the precision frequency source. Equipment is presently being developed to provide automatic substitution, without loss of count, of other oscillator sources in the event of a failure of the rubidium controlled oscillator.

Loran-C pulses from the East Coast chain are used to define epoch time. A computed value of the delay to be expected in receiving the Loran-C pulses at WSMR was obtained from the USN Oceanographic Office and subsequently verified by means of a traveling clock trip from the Naval Observatory.

The IRIG time code outputs (both modulated carrier and dc level shift) of the three generators are compared for amplitude and/or time displacement errors. There is automatic switchover to the secondary generator when an error is detected. Amplitude error limits are switch selectable at ±5%, ±10%, and ±20% with operation usually at the ±20% setting. A time displacement error is defined as ±10 microsecond time difference.

Battery backup is used on the rubidium controlled oscillator and on the pulse rate dividers down to the 1 pps point.

Time is generated one millisecond early and time codes at the user's location are brought "on time" by means of tapped delay line sections having 399 microseconds delay in 1 microsecond increments.

6. NASA George C. Marshall Flight Center

Timing signals at George C. Marshall Flight Center are generated by a three-channel time generation system. Three identical time code generators are driven by one of two crystal oscillators.

The one pulse per second outputs of the three time code generators are compared in both phase and amplitude.

If the 1 pps output of the generator selected as the "master" does not compare with the 1 pps signals from the other two generators by more than 500 $\mu$seconds, or if the amplitude decreases to less than 50% of normal, timing distribution is automatically switched to the output of the second generator. If the amplitude of the 1 pps output of the second generator decreases to less than 50%, timing distribution is automatically switched to the output of the third generator.

## IV. SUMMARY OF TIMING DISTRIBUTION TECHNIQUES

### A. GENERAL

The term "timing distribution" deals with the process of transmitting timing signals from the generator facility to all of the instrumentation devices which use the timing signals in their various forms.

This section will deal with the timing distribution from the over-all system point of view and will describe representative systems of each type.

Since timing distribution involves time transmission from station to station and time code distribution within a station, the material of Section I B and C of the First Semiannual Report will be referenced.

The typical timing system consists of a central time code generation facility and several remote facilities with a variety of instruments which use the time codes such as tape recorders, cameras, oscillograph recorders, strip chart recorders, plotters, etc. These remote facilities can be fixed or mobile, located near the central time code generation facility or up to 100 miles from the generator facility.

Timing signal distribution systems can be divided into two general categories -- systems using radio propagation as the transmission medium and systems using wire circuits as the transmission medium.

The choice between radio or wire distribution to deliver timing signals to an instrumentation station is generally influenced by factors such as

1. Will the instrumentation station be located in an area not now served by wire facilities?

2. Will the instrumentation station move frequently from site to site?

3. Does the instrumentation station require timing signals while in motion (test aircraft, rocket sled, etc.)?

4. Are there already existing communication circuits of adequate bandwidth and delay stability characteristics to the desired instrumentation site?

5. Are useable radio frequency bands available on an exclusive use basis?

6. Can interference from unauthorized radio transmitting be prevented?

7. Are bandwidths in excess of 10 kHz required?

8. Complexity of transmission or terminal equipment that can be tolerated.

## B. RADIO DISTRIBUTION

### 1. General

Radio distribution of timing information is used at many ranges and at some ranges as, for instance George C. Marshall Space Flight Center, radio is the primary distribution system. Radio distribution systems make possible the delivery of timing information to moving vehicles and to instrumentation stations that are frequently moved from one field location to another. Radio distribution systems typically have less delay than wire circuits of equivalent bandwidth, have a more linear phase shift versus frequency characteristic, and have delays that are readily monitored at each location.

Radio distribution circuits are typically via carrier frequencies of 140 mHz and higher with many facilities installing equipment in the 1750 to 1850 mHz region. These carrier frequencies of 140 mHz and higher are not normally reflected from the earth's ionosphere and have highly attenuated ground wave signals so that they are primarily dependent on "free space" or "line of sight" propagation paths.

2. Radio Distribution Table

General

The principal characteristics of representative radio distribution systems as listed in Table 2 are briefly described in the following sections.

Carrier Frequency

Distribution of timing information by radio requires a propagation path that is quite stable.

TABLE 2

TIMING DISTRIBUTION BY RADIO CIRCUITS

| FACILITY | CARRIER FREQ IN MHz | PUBLISHED EFFECTIVE RADIATED PWR IN WATTS | MAXIMUM DISTANCE IN MILES | TYPE OF MODULATION | CHAN WIDTH IN kHz | MOD/ DEMOD DELAY | MODULATING SIGNAL TYPE | TERMINAL EQUIPMENT | TERMINAL DELAY | DELAY COMPENSATION |
|---|---|---|---|---|---|---|---|---|---|---|
| AFETR Cape Kennedy<br><br>See page 137 of IRIG 103-63 | 1750 | | 35 | PCM/AM | | | Time multiplexed, level shift codes, 80 channels, 1000pps frame rate, 100,000pps bit rate.<br>IRIG A time code "1" transmitted as presence, "0" as absence on one channel.<br>Entire code is reconstructed using time codes "1" plus 1k pps, 100pps, 10pps from other channels. | Demultiplexing units. | | Adjustable 0-200usec delay-resolution 1usec.<br>Signal transmitted 1205usec early. |
| AFPGC Eglin AFB | 141.2 | 500 | 30 | FM | ±30 | | Level Shift IRIG A 10kHz Carrier. | | | No delay compensation |
| | To be assigned | 500 | 30 | FM | ±15 | | IRIG B, 1kHz Carrier and IRIC C, 100Hz carrier. | IRIG B and C are separated with band pass filters then delivered to users via driver circuits. | | |
| AFFTC Edwards AFB RF System described in AFFTC Tech Report 65-1 | 1720 | Approximately 1000 | System design provides 40db S/N ratio at free space distance of 40 miles. | PCM/AM Bi-phase coding, decrease of carrier amplitude at "Bit Time" represents logic "One". 7 bit Barker word or its complement transmitted on alternate frames, e.g. 1110010---0001101<br>3 successive sync errors defines "Loss of Sync". "Flag" bits in time code indicate sync errors. Flagged frames should be treated with discretion. | | | Time multiplexed, level shift codes, 50 channels, 1000cps frame rate, 50,000pps bit rate. | Demultiplexing Units. | | Adjustable 0-1MS plug-in delay-resolution 1usec.<br>Signal transmitted 2000usec early. |
| NOTS China Lake | 141<br>1770 on test and development basis | 200 | 40 | AM | 30 | * | IRIG B | Accepts IRIG B and separates modulation signal from the carrier. The carrier is used to phase-lock the 1kHz local clock which is divided down to drive the accumulator. The demodulated signal is used to compare and/or correct the accumulator.<br>Accumulator is scanned to regenerate IRIG B or other IRIG codes as required. | * | * Distribution delay compensation limited to inserting only radio propagation delays into computer data reduction programs.<br>Radiated signal is "on time" at distance of 3 miles from transmitter. |
| PMR Point Mugu | 140 band | 250 at Laguna Peak | 200 Airborne | AM | | | IRIG B and E | | | |
| | 140 band | 250 at San Nicolas Island | | | | | IRIG B | | | |
| WSMR | 350-400 | 100 | 60 Nom | FM<br>Time Division Multiplex<br>9 channel plus sync<br>10k frames per second | 800 | 20usec Chan 1 plus 10usec per chan. | IRIG Codes plus Pulse Rates | Demultiplexed DC Shift Codes | | No delay compensation. |
| | 1800-1850 | 10 | 60 Nom. | 1000F9/500A9 | 1000 | 105usec | IRIG Codes plus Pulse Rates | DC Shift and Carrier Formats. | | Digital delay compensation |
| | 139-144 | 100 | 60 Nom | 24A9 | 24 | | IRIG B (1kHz Carrier)<br>IRIG C (6kHz Carrier)<br>IRIG E (10kHz Carrier)<br>Lift-Off | Standard Wire Line Type, Timing Terminal Modules (Pen Amplifiers, Neon Drivers, AGC Amplifiers, etc.) | | Delay compensation may be added by use of external standard passive delay unit. |
| | 139-44 | 100 | 60 Nom | 60A9 | 60 | | IRIG A (10kHz Carrier) | Standard Wire Line Type, Timing Terminal Modules (Pen Amplifiers, Neon Drivers, AGC Amplifiers, etc.) | | Delay compensation may be added by use of external standard passive delay unit. |
| | 300-400 | 50 | 200 Airborne | 3A9 | 3 | | IRIG B or E | | | |
| NASA George C. Marshall Space Flight Center | 226.5 | 2.5 | 15 | FM/FM | Approx 300 | | FM Multiplex of standard IRIG Telemetry VCO'S. (7.5% dev.)<br>CODE — VCO<br>Modulated Carrier<br>IRIG B — 70kHz<br>Level Shift<br>IRIG B — 40kHz<br>IRIG C — 5.4kHz<br>AMR B1 — 2.3kHz<br>AMR B1 — 30kHz<br>AMR D5 — 52.5kHz<br>100kHz standard frequency, 120kHz tape speed compensation | Receiver with appropriate telemetry discriminators to provide serial time codes directly. | | Time codes are monitored using receiver, discriminator, and standard data filter. This removes modulate/demodulate delays as a factor leaving only propagation delays of approximately 5.37usecs per mile. |

IRIG Document 105-63 recommends radio frequencies to be used for instrumentation timing. In the VHF region (30-300 mHz), five frequencies are recommended -- 139, 140, 141, 142, and 143 mHz. In the UHF region (300-3000 mHz), frequencies in the band from 1710 to 1850 mHz are recommended with frequencies assigned on integral mHz increments to allow easy multiplication from and synchronization to the basic timing generator.

Radio transmissions in both the 140 mHz and the 1800 mHz region are substantially limited to distances at which "line of sight" conditions prevail between the transmitting and receiving antennas. Consequently, the same frequency can be assigned for use at two or more geographic areas provided that these areas are separated by 200 to 500 miles, depending on whether operations involving aircraft are contemplated. When transmission to aircraft operating at altitudes in excess of 40,000 feet are considered, 500 mile or greater separation is desirable between stations using the same frequency.

Since the path of the radio waves in the earth's lower atmosphere is slightly curved, the effective radio "horizon" for "line of sight" conditions is approximately the same as if the earth's radius were increased by 4/3. The distance from a transmitting antenna at a height of H feet to the radio horizon is approximately equal to $\sqrt{2H}$ statue miles. Aircraft operating at altitudes of 40,000 feet

Effective Radiated Power (ERP)

This is the transmitter output power decreased by the power lost in the transmission line between transmitter and antenna, and increased by the power gain of the antenna. In typical installations, the antenna gain is achieved by confining the radiation into a relatively narrow vertical angle while maintaining an omni-directional horizontal pattern.

The "free space" path attenuation between two 140 mHz isotropic antennas separated by 30 miles is approximately 110 db. Consequently, a radiated power of one watt at a distance of 30 miles will deliver to the receiver a -110 dbw signal. The minimum useable signal (20 db signal-to-noise output) for a receiver having a 30 kHz bandwidth and a 3 db noise figure is -136 dbw. The received -110 db signal will be 26 db in excess of the previously defined -136 dbw minimum useable signal level. This 26 db excess signal provides a margin to offset the effects of multipath signal cancellation, equipment degradation, temporary path obstructions, etc. From the above considerations it can be seen that a large amount of radiated power is only required when transmission is attempted to a receiver located beyond the "line of sight" distance. At distances substantially beyond the "radio horizon" the attenuation increases rapidly.

To minimize interference between radio systems operating on different radio frequency channels, but in the same geographic area, IRIG Document 105-63 recommends that the ERP of spurious emissions outside the assigned bandwidth be less than -25 dbm (25 db below 1 milliwatt). To keep spurious emissions below this -25 dbm level requires attenuation of spurious frequencies proportional to the ERP. As an example, a transmitter having an ERP of 1000 watts will require that all spurious frequencies be 85 db below the normal output level.

Maximum Distance (Ground station to ground station)

This is typically limited to distances only slightly beyond the "radio horizon." Systems which have 30 to 40 mile ground-to-ground maximum operating distances with moderate antenna heights can have "ground-to-air" maximum distances of 200 + miles, depending primarily on the aircraft altitude.

Type of Modulation

The two basic modulation systems are: AM (amplitude modulation), and FM (frequency modulation). The timing information which modulates the carrier may be coded in one of several ways, consequently the modulation is frequently listed as a combination of the coding and modulation, e.g., pulse code modulation/amplitude modulation (PCM/AM). Other modulation types are: FM/FM, in which the transmitted radio frequency carrier is frequency modulated by the combined sum of several subcarrier oscillators that are, in turn, frequency modulated by the data signals (time codes).

Pulse duration modulation, when used to transmit multichannel analog information, is a train of pulses. The duration of each pulse in the train is varied between a minimum and a maximum duration in accordance with the value of each data channel. Time code information producing PDM is a simplified version of the analog case. The time code information is coded using only two or three discrete pulse durations.

Pulse amplitude modulation, when used to transmit multichannel analog information, is a train of pulses. The amplitude of each pulse in the train is varied between a minimum amplitude and a maximum amplitude in accordance with the value of each data channel. Time code information producing PAM is a simplified case. The amplitude level of the code carrier usually has only two amplitude levels. The larger level indicating the presence of a code bit whose actual value is width coded.

Pulse code modulation is a special type of PAM in which only two amplitude levels are used, "on and off" or "minimum and maximum." Each individual bit of data (tens of hours, units, minutes, etc.) is coded using the presence and absence of a group of sequential data bits whose values are usually arranged in ascending or descending binary values.

Many time codes combine this type of modulation with the addition of width coding rather than presence/absence coding to indicate whether each binary digit should be included in determining the total value of a particular group of bits. The fact that pulses are transmitted for both data zero and data ones makes the code "self-clocking" where the presence/absence coding requires a separate clock rate to control the time at which the pulse presence/absence determination should be made. This clock rate can be extracted from presence/absence coded information using a stable oscillator whose frequency is servoed to the data rate. To successfully servo an oscillator to the presence/absence coded information, there must be a required minimum percentage of data ones (pulses present) and a maximum allowable interval between data ones.

Channel Widths

Channel width can have two interpretations -- one being the difference between the minimum and maximum frequencies which a station is authorized to radiate, or channel width can be the difference between the minimum frequency and the maximum frequency actually radiated at power levels in excess of -25 dbm. A station should not radiate significant energy on frequencies outside the authorized channel width but, when the significant frequency components of the data to be broadcast is less than the authorized channel width, the occupied channel width will be narrower than the authorized channel width.

The channel width required (or desirable) for the transmission of time code information will depend on the accuracy and stability with which the time code information must be recovered or re-generated at the output of the radio receiver. As an example, IRIG B time code in the level shift form at the generator output will have rise and fall times of one microsecond or less and, in order to have a faithful reproduction of this pulse at the receiver output, the radio transmission channel width should be at least 1 mHz. These same pulses, having a rise time of 1 microsecond, can be transmitted over channel widths of 100 kHz with regenerated output pulses having widths and rise times that match those of the time code pulses as generated within ±1 microsecond, providing that the signal-to-noise ratio is above 30 db and that AGC circuitry is effective in keeping the peak value of the pulses to a fixed value.

Signal-to-noise ratio can be traded for bandwidth to allow time information, precise to one microsecond, to be transmitted over channel widths of 100 kHz. The 100 kHz channel width allows a 10% to 90% rise time of approximately 10 microseconds = 8%/$\mu$second. If the AGC controlled output pulse amplitude is 1 volt ± .05 volts, then the 50% amplitude part will be .5 volt ±.025 volts and at a rise rate of .08 volts/$\mu$second will have time variation of $\frac{.025}{.08}$ $\mu$sec, approximately .31 $\mu$sec due to amplitude variations. Noise that is 3 db below the 100% signal level will have an RMS value of .03 volts and will vary the time of attainment of the .5 volt level by $\frac{.03}{.08} = .37\ \mu sec$. Variations of $\pm .03$ V in the .5 volt threshold of the amplitude discriminator will vary the time of 50% amplitude detection by $\frac{.03}{.08} = .37$ microsecond. The RMS error in detection of the 50% level point will be $\sqrt{.31^2 + .37^2 + .37^2}$ microseconds equals .61 microseconds.

## Modulate/Demodulate Delay

Timing signal transmission over radio links have three principal delays. First, a delay between the input to the modulator section of the transmitter and the actual modulation of the radiated signal, and second, a delay due to finite travel time of the radiated signal between transmitting and receiving antennas, and third, the delay between the modulated input and demodulated output of the radio receiver.

The modulate/demodulate delays will be principally dependent upon the bandwidth of the transmitter and receiver.

## Signal Type

Timing information transmitted over radio links is separable into three catagories; (1) multichannel time division multiplexed, (2) multichannel frequency multiplexed serial time codes, and (3) single channel serial time codes.

Facilities using a large variety of timing codes and pulse rates have used two differing radio distribution philosophies. One approach, as typified by the NOTS system, is to transmit only one time code as the synchronizing input to a terminal unit capable of generating any desired codes and pulse rates. The second approach, as typified by AFETR and AFFTC, is to distribute a multiplicity of codes and pulse rates using time division multiplexing to distribute 50 or more types of information so that very few, if any, time codes and/or pulse rates require assembly or generation in the terminal unit.

A good compromise approach seems to be typified by the WSMR system in which 9 channels of time codes and pulse rates are time division multiplexed for distribution and any additional rates and/or codes required are generated by additional terminal equipment.

Terminal Timing Equipment

Terminal timing equipment is defined as equipment used to process the timing information delivered at the output of the radio receiver to prepare it for recording or interpretation.

Some radio transmitted time codes require no terminal timing equipment as, for instance, the modulated carrier form of IRIG B which can be taken directly from the radio receiver output and applied to the input of a magnetic tape recording system.

Timing terminal units are used to --

1. Demultiplex received multichannel timing information.

2. Reform a received time code from the form suitable for transmission, to a form meeting the requirements of the using equipment.

3. Reformat the received time code to meet the requirements of the user. For instance, a received IRIG B code might be stored in a register and scanned out at a slower rate with the same or different form of coding. An example would be the storage of IRIG B and the subsequent scan out of NASA 20-bit code.

4. Stabilize the delivered time code by generating a time code that is slaved to the received time code. This terminal unit is a complete time code generator whose crystal oscillator is phase locked to the long-time average of the incoming carrier of the received time code and whose generated code is compared against the received time code for information content and for time delay. The phase locked local oscillator has sufficient stability to maintain an accurately synchronized time code output in the absence of an input signal and to require infrequent correction so that apparent frequency differences between the incoming carrier frequency and the locally generated frequency can be averaged over a long enough period to remove the short-term effects of noise and jitter.

## Terminal Delay

This delay in the terminal unit can be detection delay due to the effective signal bandwidth of the terminal device or it can be an output delay as in the case of relay closures commanded by the received time code.

## Delay Compensation

Delays in distributed time code information can be compensated for by generating time codes that are early by an amount of time slightly greater than the longest distribution delay to be corrected and adding sufficient fixed delays to each received signal to bring it "on time."

In cases where only a minority of customers have distribution delays that require correction, the cost of needlessly correcting the majority of customers should be weighed against the cost of a slaved repeater whose regenerated output can be adjusted to be "on time" and can be maintained "on time" by using delayed outputs for time comparison with the distributed signal from timing central.

3. Description of Representative Radio Distribution Systems

## General

This section of the Time Code Study presents a brief description of representative radio distribution systems which are in existence at some of the National Ranges, Service Ranges, and NASA facilities listed in Table 2.

IRIG Document Number 103-59, Instrumentation Timing Systems Brochure, is presently in the process of revision and will contain more complete information regarding the majority of these timing systems.

<u>Air Force Eastern Test Range -- Cape Kennedy</u>

The primary radio distribution system at AFETR is an 80-channel time division multiplex system transmitted via UHF radio on a carrier frequency of 1750 mHz.

The time division multiplex is generated at each central timing facility by sampling 79 channels of dc level shift time codes and pulse repetition rates at 100 kHz rate. The system frame rate is 1000 frames per second. Each frame consists of the 79 information channels and a 1 kpps frame marker channel (which occupies 800 $\mu$seconds) and a 200 $\mu$second vacant period at the end of the frame. This information is used to synchronize the decoder in the timing terminal units.

The serial wave train is transmitted by presence/absence coding with the presence of a "one" providing a change in carrier output from 10% to 100% power.

The sampled data is 1205 $\mu$sec early with respect to "on time" at the multiplexer. The serial data is demultiplexed by the decoder in each of the terminal timing units and presented in parallel form at the end of each frame. Thus parallel data output is early with respect to "on time" by 200 $\mu$seconds, less the radio propagation time from the transmitter to the decoder. The parallel readout of selected channels can then be delivered "on time" by adding a fixed delay such that radio transmission delay plus fixed delay equals 200 $\mu$seconds.

Each terminal decoder unit can provide outputs of 40 channels from the 80 channel frame. The outputs can be any combination of dc level shift time codes or pulse rates.

The system delivers output signals with leading edges which are "on time" with respect to the Central Generator within 1 $\mu$second. Pulse-to-pulse spacing (or jitter) is accurate to within 0.1 $\mu$second.

IRIG A, which has a 1 kpps repetition rate is reconstructed at a terminal site by using the 1 kpps frame marker channel, the "binary ones" channel, and 100 pps rate channel for position identifiers.

Air Force Flight Test Center -- Edwards Air Force Base

AFFTC utilizes a 50-channel time division multiplex system to distribute timing signals via UHF radio on a carrier frequency of 1720 mHz.

The time division multiplex is generated at the central timing facility by sampling 50 channels of time code and pulse rate information at a 50 kHz rate, providing a PCM wave train with a frame rate of 1000 frames/second. Seven of the 50 channels are used to transmit a 7-bit Barker word or its complement on alternate frames for frame synchronization purposes.

The biphase coded PCM wave train is transmitted from the central timing facility to the UHF transmitter located on top of a mountain via a microwave system using the full base bandwidth of the system.

The multiplex signal is transmitted to remote terminal timing units throughout the range on the 1720 mHz UHF radio channel.

Terminal timing units provide a demultiplexer which is synchronized by means of the Barker sync words. Each output channel of the demultiplexer contains a flip flop storage element. All storage elements are clocked with a single clock at the end of each 1 ms frame to provide dc level shift time codes or pulse rates which are coincident and 1 ms late, relative to the beginning of the frame.

The timing terminal units have optional plug-in delay units that provide a delay adjustment range of zero to one millisecond with one microsecond resolution. The units can be used to provide the necessary delay to compensate for propagation delay to a particular timing terminal unit.

The time division multiplex distribution system is capable of reconstructing time codes with bit rates as high as 1 kpps.

Reconstructed serial time code and pulse rate outputs from the demultiplexer are routed to the instrumentation at the particular remote site via neon drivers, relay drivers, pen drivers, line drivers, etc.

Naval Ordnance Test Station -- China Lake

The primary time code distribution at NOTS is accomplished by VHF radio at 141 mHz. AM type IRIG B time code is used to amplitude modulate the carrier. Timing information is transmitted via the VHF link from the Central time code generation point to timing terminal units at remote sites.

A typical timing terminal unit has one input which receives the IRIG B signal from the output of the timing receiver. The input circuit demodulates the time code word and extracts the 1 kpps rate from the IRIG B carrier. The 1 kpps rate is used to phase lock a local 1 kpps free-running clock. This local clock signal is divided down to 1 pps and counted in an accumulator in IRIG form. The contents of the accumulator is checked during each time frame by the demodulated code word derived from the input signal.

IRIG B and other slower IRIG codes are regenerated as required by the instrumentation at each site by scanning the accumulator at the appropriate rate.

Unlike other timing terminal units which have local stable crystal oscillators, this type of timing terminal unit is highly dependent on the received signal from the central generator. However, the local 1 kpps free-running clock which is phase locked to the IRIG B 1 kHz carrier reduces detection jitter from about 80 microseconds to about 8 microseconds.

A timing receiver is located in the Central timing facility about 3 miles from the transmitter. The time code generator is adjusted to provide the system "on time" signal at the output of the monitor receiver, thus eliminating the delays in the transmission circuit from the generator to the transmitter and the modulate/demodulate delays of the transmitter and receivers. Radio propagation delays to all instrumentation sites on the range are compensated for in the data reduction computer programs.

NOTS is presently using a UHF band at 1770 mHz on a research and development basis. The present plan is to broadcast the IRIG A time code in the same manner as the IRIG B time code is broadcast on the VHF channel.

White Sands Missile Range

The primary radio distribution system now in operation is a 20-channel time division multiplexed system using carrier frequencies in the 350-400 mHz region. This present system has a 5 kHz frame rate and a 100 kHz channel rate. Only 10 of the 20 channels are currently in use (1 sync and 9 data). A new 10-channel system using carrier frequencies in the 1800-1850 mHz region with a

10 kHz frame rate and a 100 kHz channel rate is presently being evaluated, and will eventually replace the present system.

The present 350-400 mHz system uses a three-level (advance, normal, retard) phase modulation of an FM transmitter. FM receiver discriminators recover bipolar pulse outputs from which the codes and rates can be reconstructed.

Decoder units of the present system output the information from each channel as received, consequently, there is a 10 microsecond per channel delay and channel 9 information is delayed 80 microseconds relative to channel 1 information.

Decoder units of the new (1800-1850 mHz) system will assemble data from all channels in a shift register and output all channels simultaneously.

To cover the large geographic area of WSMR, the Radio Distribution System uses a mountain top repeater station operating on a different frequency than the transmitter at the central timing facility. This use of translated frequencies allows users at intermediate distances from the two transmitters to use the stronger of the two signals in areas where coverage of the two transmitters overlaps.

George C. Marshall Space Flight Center

Practically all timing is distributed in the area via an FM/FM radio system operating at 226.5 mHz. Three of the AMR time codes (B1, D1, and D5) plus IRIG B and C are transmitted. Each time code frequency modulates a voltage controlled oscillator whose output is linearly mixed with other VCO outputs plus two fixed frequencies of 100 kHz and 120 kHz. This composite waveform then frequency modulates a 2.5 watt 226.5 mHz transmitter.

Standard IRIG telemetry subcarrier frequencies are used (as tabulated below). Consequently, any desired time code or codes can be recovered from the received composite signal by the use of standard telemetry band separation, and discrimination equipment. The standard 7.5% deviation is used on all channels.

| Time Code or Signal | VCO Channel |
|---|---|
| IRIG B (modulated carrier form) | 70 kHz |
| IRIG B (dc level shift form) | 40 kHz |
| IRIG C | 5.4 kHz |
| AMR B1 | 30 kHz |
| AMR B1 | 2.3 kHz |

The AMR B1 code is transmitted on the 30 kHz channel to provide time code information with a high degree of resolution to certain using facilities.

Modulate/demodulate delays in the transmitter and receiver are eliminated in the distribution system by steering the time generation system to produce the "on time" signals at the output of a receiver/discriminator used to monitor the transmitted signal in the time generator facility. The distribution delay is thus limited to the radio propagation delay from the transmitter to the user.

## C. WIRE DISTRIBUTION

### 1. General

Practically all facilities involved in timing utilize some wire distribution in the system. Table 3 is a summary of major wire distribution systems utilized at the National Ranges, Service Ranges, NASA facilities, and Tracking Stations listed.

The Communications and Data Transmission Committee of the IRIG Tele-Communications Working Group is studying the problem of accurate time code distribution, and are planning to publish an IRIG document in early 1967. that will specify in readily measureable terms the characteristics which a transmission path and the signal itself must have in order to deliver accurate time information. Mr. Spurgeon E. Watford of WSMR is chairman of this committee.

### 2. Wire Distribution Table

General

The principal characteristics of representative wire distribution systems as listed in Table 3 are briefly described in the following section.

Cable Type

Cables used to transmit timing signals fall into two categories -- phone lines and wide-band pairs or coax. In some cases these cables are specifically chosen for this service, but in many cases

TABLE 3

## TIMING DISTRIBUTION BY WIRE CIRCUITS

| FACILITY | CABLE TYPE | SIGNAL TYPE | DELAY PER MILE | MAXIMUM DISTANCE IN MILES | TERMINAL EQUIPMENT | TERMINAL DELAY | DELAY COMPENSATION |
|---|---|---|---|---|---|---|---|
| AFETR Cape Kennedy | | Pulse position codes by pairs of bi-polar pulses.<br>1000Hz sine wave. | | 10<br>10 | Units which reconstitute width modulated codes for distribution to instrumentation requiring dc level shift outputs.<br>Above units accept 1000Hz signal and provide adjustable phase delay and remodulate reconstituted width codes for instrumentation requiring precise modulated carrier signals. | | None.<br>Those customers whose synchronization requirements cannot be met with wire distribution will be supplied via radio distribution system. |
| NASA Merritt Island Launch Area | 19 gauge telephone pairs<br>19 gauge telephone pairs<br>19 gauge telephone pairs | Early signal from central timing to synchronize sub-central generators.<br>Pulse position codes by pairs of bi-polar pulses.<br>Carrier modulated with $\sin^2$ envelope.<br>1000Hz sine wave. | | 4.5<br>1000 ft.<br>20 with regeneration repeaters. | Sub-central generators.<br>Above units accept 1000Hz signal and provide adjustable phase delay and remodulate reconstituted width codes for instrumentation requiring precise modulated carrier signals. | | Early code delayed to provide time signals on time at sub-central generators.<br>No delay compensation from sub-central generator to recorded signal.<br>Delays measured with traveling clock. |
| AFFTC Edwards AFB | Base Communications System | Modulated Carrier IRIG B | | 5 | Ground support station for aircraft time code generators. | | None. |
| NOTS China Lake | RG8/U coaxial | Modulated Carrier IRIG C<br>Various pulse rates<br>IRIG A,B | 8usec | 1 | Translators | 1MS | None. |
| PMR Point Mugu | Multiconductor 19 gauge | Modulated Carrier IRIG B,C,D and E, all with 1kHz Carrier | | Less than 5 | Timing Terminal Units. | | None.<br>Future plans call for early time code generation and compensating delays at terminal locations. |
| WSMR | Multiconductor 19 gauge and open wire lines | Modulated Carrier IRIG A,B,C, D and E<br>Dual Lift-offs | | 20 | Translator Generators<br>Timing Terminal Units | ±1usec<br>10usec to 50usec | Radars, Special Instrumentation<br>Time Generated 1MS Advanced. |
| NASA Goldstone Tracking Station (Deep Space) | | | | | | | Distribution limited to modulated and dc level shift codes distributed to magnetic tape recorders and strip chart recorders in the same room with the generator. |
| NASA Mojave Tracking Station (Orbital) | | | | | | | Distribution limited to modulated and dc level shift codes distributed to magnetic tape recorders and strip chart recorders in the same room with the generator. |

the cables used to distribute time code signals are part of an existing Base Communications Plant whose cables were selected for reliable voice communications.

The bulk of the timing signals are distributed by means of phone lines (600 ohm twisted pairs). In general, only primary frequency signals are transmitted via wide-band cables.

Signal Type

Time code signals are commonly transmitted from the time code generator facilities to remote timing terminal equipment.

Time code signals to be distributed via wire circuits are usually in a form that does not require extremely low frequency response on the part of the communication circuit. Two common forms are the width-coded amplitude-modulated carrier and the bipolar pulse in which the pulses define the leading and trailing edges of the width-coded signal. Terminal equipment can reconstruct the time code in its width-coded dc level shift form. Modulated carrier outputs may also be constructed by the terminal unit if a carrier frequency is supplied via a separate circuit.

Special forms of amplitude modulation such as the sine squared envelope used at NASA Merritt Island on lengthy circuits are chosen to provide maximum rise time consistent with acceptable "cross talk" interference.

Delay Per Mile

Time code signals transmitted by wire circuits can have delay per mile figures that range from less than 6 microseconds per mile for open wire line to more than 50 microseconds per mile for multi-conductor cables.

Maximum Distance

The distance that a particular time code can be accurately transmitted depends upon the quality of the wire circuit and the complexity of the terminal device that interprets or regenerates the time code.

The entries in this column are the distance over which the listed time codes are operationally distributed and not the maximum distance which could be obtained.

Terminal Equipment

Terminal timing equipment accepts the time code information from the distribution system and delivers time code information to the user. The timing terminal unit can be a single amplifier which provides isolation (buffering), impedance matching, and power gain between the transmission line and the using equipment. More elaborate timing terminal units perform a variety of functions such as filtering, detecting, and regenerating a noise-free time code output, or reshaping the time code from a modulated carrier input form to controlled current pulses in a neon lamp.

Terminal units may approach time code generators in complexity and be capable of outputting a wide variety of time codes and pulse rates.

## Terminal Delay

This is the effective delay between the time code as received and the time code output from the terminal unit. When the terminal unit outputs are in the form of mechanical contact closures (relay contacts), then delays can be from 1 to 5 milliseconds. When the terminal outputs are electrical signals, then the delay will depend on the method of detection and the bandwidth of the amplifier/ detector/output driver circuits.

## Delay Compensation

Compensation for distribution delays can be achieved by adjustment of the time of delivery of the time code signal, or by adjustment in the data reduction process.

When compensation is achieved by adjustment of the time of delivery, the time codes are generated early by a time increment greater than the maximum distribution delay and variable delay circuits are added at each site to bring the delivered signals "on time."

Delay compensation can also be achieved in terminal units which actually generate a time code controlled by comparison to the delivered time code signal. This comparison process can be adjusted to maintain the generated code in advance of the received time code signal by an amount of time equal to the distribution delay.

3. Description of Representative Wire Distribution Systems

General

This section of the Time Code Study presents a brief description of representative wire distribution systems which are in existence at some of the National Ranges, Service Ranges, and NASA facilities listed in Table 3.

IRIG Document Number 103-59, Instrumentation Timing Systems Brochure, is presently in the process of revision and will contain more complete information regarding the majority of these timing systems.

Air Force Eastern Test Range -- Cape Kennedy

Timing distribution is accomplished at AFETR by means of both radio link and telephone lines. Time signals are distributed by telephone lines to areas within 10 miles of each central generator.

The majority of the timing information distributed via phone line is transmitted to terminal timing units in the form of bipolar pulse pairs and 1000 Hz sine wave signals. The leading edge of each width-coded time code bit is transmitted as a pulse of one polarity and the trailing edge as a pulse of the opposite polarity. Each pair of pulses is reconstituted to the original dc level shift width-coded time signal in the terminal unit. The modulated carrier form of the time code signals are regenerated in the terminal unit by modulating the 1000 Hz sine wave signal received on a separate phone line by the reconstituted dc level shift signal. The terminal timing units contain circuits to phase shift the 1000 Hz sine wave to cause cycle crossover to be coincident with the leading edges of the dc level shift codes.

There is a limited amount of time code signal distribution in the form of amplitude modulated carrier signals on phone lines, as, for instance, IRIG B on a 1000 Hz carrier. AFETR personnel have found that this form of the time codes can be most accurately delivered to users by transmitting the width modulated information in the bipolar pulse position form and modulating the separately transmitted carrier as described above.

Other codes are transmitted as presence-absence data bits on one circuit and position identifier bits on a second circuit. This type of code is used where time data is being entered into a shift register for storage.

NASA Merritt Island Launch Area

Timing distribution at the Merritt Island Launch Area is performed entirely by wire circuits.

Timing signals are generated by a central time generation station and two subcentral time generation stations. The two subcentral stations are synchronized by early signals transmitted from the central time generation station and delayed to provide signals which are "on time" with the central time generation system.

Timing signals are distributed from the central time generation system and the two subcentral time generation systems to timing terminal units at remote instrumentation sites via telephone pairs.

Timing information is transmitted to the timing terminal units in the form of bipolar pulse pairs and 1000 Hz sine wave signals over distances up to 4 miles.

The leading edge of each width-coded time code bit is transmitted as a pulse of one polarity and the trailing edge as a pulse of the opposite polarity. Each pair of pulses is reconstituted to the original dc level shift form in the timing terminal unit. The modulated carrier form of the time codes is regenerated when required by a modulator circuit which uses the reconstituted dc level shift form of the signal to modulate the 1000 Hz sine wave transmitted to the timing terminal unit on another telephone line. The timing terminal unit contains a circuit to phase shift the 1000 Hz sine wave to cause cycle crossover to be coincident with the leading edges of the dc level shift code.

No delay compensation is provided in the timing terminal units. Propagation delays are measured by means of portable clock and used in data reduction, if required.

The timing terminal units provide outputs required for the instrumentation at each site via neon drivers, relay drivers, line drivers, sine wave drivers, modulator amplifiers, etc.

Timing signals are distributed to more remote points on the facility (at distances up to 20 miles) using a series of special regenerative repeaters. This system transmits a modulated carrier signal utilizing a $sine^2$ modulation. Power for the remote repeaters is transmitted over the cable from the signal source. Repeaters are placed in the line at approximately 7-mile intervals.

John F. Kennedy Space Center document SP4-49 (Revised September 1, 1965) entitled "Timing and Countdown Systems Handbook" contains a detailed description of the NASA Merritt Island Launch Area timing system as well as other pertinent information on the subject of timing.

Air Force Flight Test Center -- Edwards Air Force Base

Wire distribution of timing signals at AFFTC is limited to distribution of IRIG B time code in the modulated carrier form to users within a few miles of the central time generation facility.

The prime user of this signal is the Ground Support Unit for a bank of portable airborne time code generators.

This unit accepts the IRIG B signal from the central timing facility and generates a local IRIG B time code and pulse rates of 1000, 100, 10, and 1 pps that are synchronized to the reference input time code to within 5 $\mu$seconds. These locally generated pulse rates and time codes are used as a reference against which the portable aircraft time code generators are compared and synchronized.

The portable aircraft time code generators are normally plugged into the Ground Support Unit. When needed, they can be installed in test aircraft. The units contain adequate battery power to enable them to continue to operate until they are installed and can operate on aircraft power.

Pacific Missile Range -- Point Mugu, California

Timing signals are distributed over a cable network operated by the Test Communications Group who accept the line driver outputs of the time code generating system and deliver signals to the timing terminal units at instrumentation sites and data processing sites.

Distributed time codes are IRIG B, C, D, and E; all with 1 kHz modulated carrier.

Primary time data users are radar data systems, telemetry system recorders, both magnetic tape and strip chart, and Askania camera recorders. Timing terminal units are used to provide a variety of required outputs at the users location and/or to provide multiple amplifier outputs for subdistribution at the instrumentation site.

White Sands Missile Range

Multiconductor 19-gauge cables and open wire lines are used to distribute timing signals at WSMR. These signals are distributed from communications centers. Timing data is delivered to each communication center using high quality wide band circuits (microwave links, etc.), and is distributed from each communication center to users within a six-mile radius of that center.

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